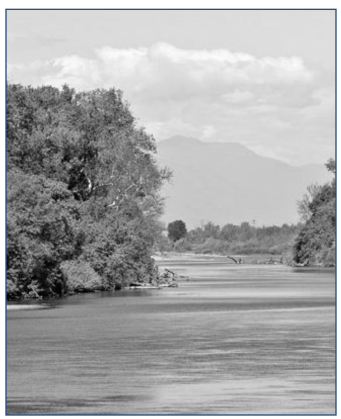
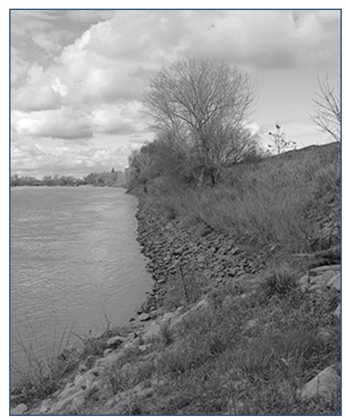
Review & Summary of: Initial Research into the Effects of Woody Vegetation on Levees Volumes I-IV

By US Army Corps of Engineers, Engineer Research & Development Center as reported by Corcoran et al. (2011)





Donald H. Gray & F. Douglas Shields, Jr.

(for the California Levee Vegetation Research Program (CLVRP) Science Team)

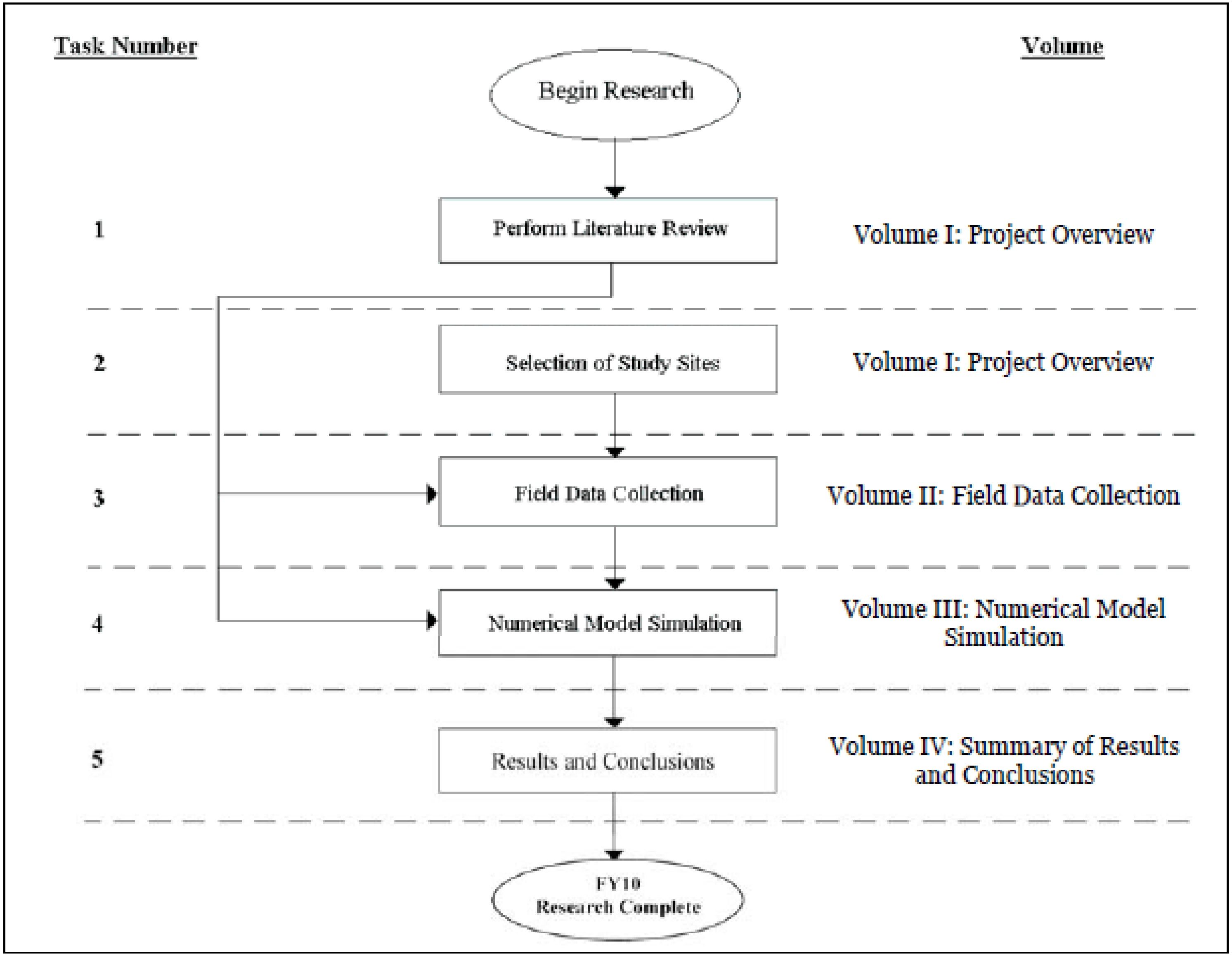
December 05, 2011

Purpose

- Summarize report for CLVRP Team not able to read/comprehend all 4 volumes;
- Review findings;
- Identify strengths and limitations;
- Suggest needed future California & national research.

Overall

- Report is unique. No other study or program of studies on this topic of similar magnitude has ever been attempted.
- Report thorough with copious figures and tables.
- Geographic scope is broad but not comprehensive.
- Many disciplines involved.
- Several cutting-edge technologies employed.
- Time constraints appear to have hampered the ability of the researchers to integrate various components of the study.



Reviewer Note: Flowchart of ERDC research approach. Tasks not performed sequentially, but concurrently due to time limitations.

Field Data and Numerical Modeling

Much of the field data collected by ERDC was not used in modeling, likely due to beginning modeling before field data results were available as ERDC acknowledges on page iii of Volume I . Use of ERDC field data in modeling appears to be limited to root strength data used in slope stability models and T-LiDAR of a fully excavated Oak tree (growing on flat ground, not a levee, at the Vicksburg site) used in 3-D model. Other model parameters (such as levee geometry, soil characteristics, local river hydrology and site geology) were set using data from existing studies and reports.

Report Presented in Four Volumes

- Literature review published (2010) separately.
- Volume I: Project overview (57pp).
- Volume II: Field data (498pp) (actual data in a separate Appendix (228pp).
- Volume III: Numerical modeling (384pp).
- Volume IV: Summary of results and conclusions (57pp).

Volume I - Project Overview

(Sets forth purpose and scope of ERDC research effort)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Initial Research into the Effects of Woody Vegetation on Levees

Volume I of IV: Project Overview

Maureen K. Corcoran, John F. Peters, Joseph B. Dunbar, Jose L. Llopis, Fred T. Tracy, Johannes L. Wibowo, Janet E. Simms, Christopher E. Kees, S. Kyle McKay, J. Craig Fischenich, Matthew W. Farthing, M. Eileen Glynn, Bryant A. Robbins, Ryan C. Strange, Martin T. Schultz, Joan U. Clarke, Thomas E. Berry, Charles D. Little, and Landris T. Lee

July 2011

Prepared for Headquarters, U.S. Army Corps of Engineers
Washington, DC 20314-1000

Project Overview Cont'd Important to Remember

- Study examined positive and negative impacts of vegetation on two key risk factors (slope stability and initiation of seepage) under a limited variety of modeled conditions.

- However, (Pg 2) "The research is not intended to weigh positive versus negative effects of woody vegetation on levees."

- Initial plans for ERDC program called for a longer, larger program that would weigh positive vs. negative effects.

- Several components were scaled back or canceled such as:
  - Overtopping effects
  - Windthrow
  - Risk/uncertainty ("fragility curves").

- ERDC report represents about 18-20 months of effort.

Project Overview Cont'd Important Limits

- Limits on type of levee and vegetation
  - Only sandy or silty sand levees
  - Only living trees
  - Only isolated trees
- Seepage analysis limited to studying the onset of internal erosion by addressing the contributing factors. Progression of seepage not examined.
- ERDC field data (root architecture and hydraulic conductivity) not used in seepage models. The 2-D seepage model was applied to particular site geometries, but hypothetical extreme conditions were used to simulate woody vegetation effects.
- Extent of field data use in modeling was limited:
  - Some field data (root strength) used in slope stability models.
  - T-LiDAR of fully excavated Oak tree (Vicksburg site – not a levee) used in 3-D model.

Project Overview Cont'd
More Limits

ERDC research did not address:

- Impact of woody vegetation within a levee channel on hydraulic conveyance.
- The role of woody vegetation contributing to scour and erosion.
- The effect of woody vegetation on levee inspection, maintenance, and accessibility to the levee for flood fighting.

Project Overview Cont’d
More Limits

Research findings tend to have multiple qualifying statements, e.g.:

- Results of analyses specific only to levees studied.
- Multiple site-factor influences.
- Case by case analysis required.
- Inconclusive test results in some cases.
- More research needed…..etc.

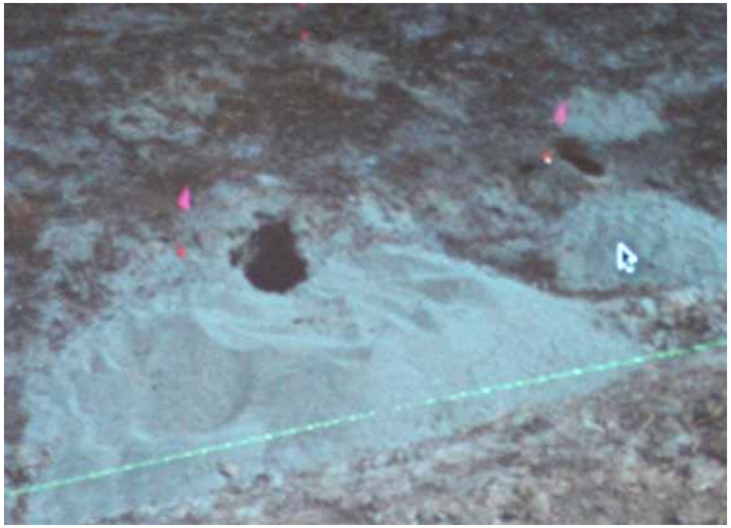
Project Overview Cont'd
More Limits

(Pg. 4) "The efforts reported in this research were focused on living, healthy woody vegetation, and apply to sandy or silty sand levees. This research did not address the performance of levee systems with the presence of dead, woody vegetation and decaying roots."

Reviewer Note: This is a critical area for further study because a policy that mandates large scale tree removals will significantly increase the presence of decaying roots unless there is a way to safely and effectively remove roots when trees are removed.

Project Overview Cont'd
More Limits

(Pg. 4). "Other areas of concern that lie outside the scope of work (SOW) are the contribution, if any, of windthrow and animal burrows to seepage."

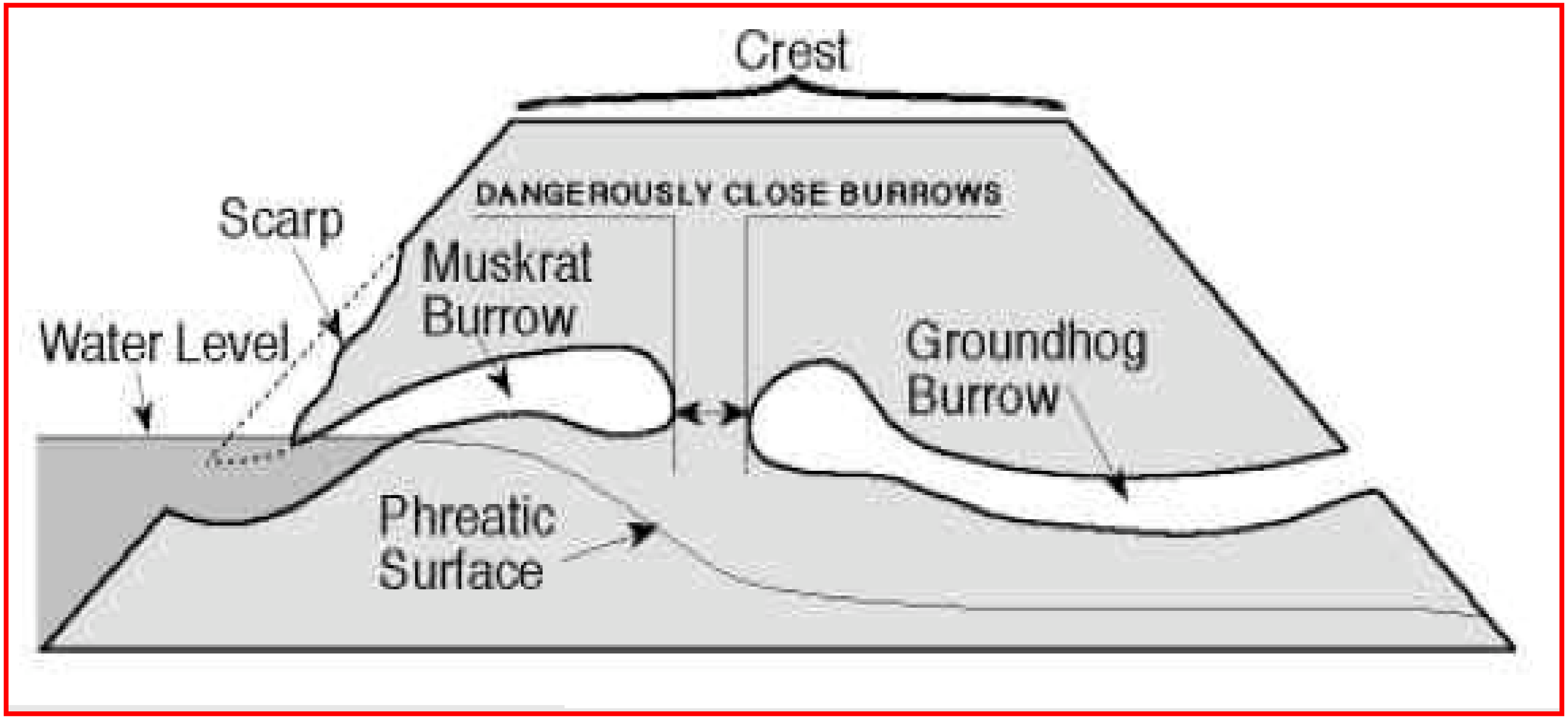


Reviewer Note: No examination of woody vegetation/burrowing animal interactions. See graphic next slide.

Recent studies show that animal burrows are a comparable if not greater cause of seepage erosion and hazard to levees than woody vegetation. See ERDC literature review.

Levee Animal Burrow Impacts

(Reported by others)



Schematic from Truckee canal failure investigation (US BuRec 2008). Also see Paul and Slaven (2009), Kelley et al. (2009).

Project Overview Cont'd
Literature Review

(Pg. 20) "In August 2007, ERDC conducted a review of the technical literature…."

Reviewer Note: The literature review is extensive and well annotated and in itself is a major contribution. It includes both peer-reviewed and gray literature. However, the review was not published until 2010, and may not have been completed in time to fully inform the research program.

ERDC report notes (on p. 6) that previous work on vegetation effects on flood control levees is rare. The literature review summarizes findings of early (circa 1980s) research that identified beneficial influence of woody vegetation on the slope stability of sandy levees, and provided an order of magnitude sensitivity analysis of effects of vegetation on seepage. However, the earlier research was hampered by less advanced techniques available then to study plant root architecture and less sophisticated stability analyses in use at that time. No study was done of root-induced piping in this earlier work.

Project Overview Cont'd
Root Characterization and Slope Stability

Root Characterization, (Pg. 7) Notes that "Research on root characterization and effects of tree roots on upland slopes is more abundant than studies directed toward woody vegetation on levees."

Reviewer Note: This finding and its significance, i.e., how levees differ in important respects from upland slopes is discussed in the narrative section of the ERDC literature review.

Slope Stability Studies, (Pg. 10) "There are numerous publications on research concerning the effects of woody vegetation on slopes and riverbanks. Although banks and slopes are not constructed features, it is beneficial to understand the techniques used in these assessments and their potential applicability to the study of woody vegetation on levees."

Reviewer Note: ERDC acknowledges numerous previous studies and their value. However, recent work on streambanks using fiber bundle model approach to simulate root effects on soil strength not fully exploited.

Project Overview Cont'd
Seepage and Piping

(Pg. 13). "…. The impacts of woody vegetation on seepage and piping through a levee embankment are much less known compared to effects on slope stability."

Reviewer Note: Work by Ziemer (1992) reported greatly increased subsurface pipe flow and sediment transport in slopes where woody vegetation had been removed. Cited in ERDC lit review.

Ziemer, R.R. 1992. Erosion, debris flows and environment in mountain regions, In Proceedings of the Chendu Symposium, July 1992, Chendu, China. International Association of Hydrological Sciences Publication No. 209. Wallingford, UK. 187-197.

Project Overview Cont'd
Levee Failure Mechanisms

- (Pg. 15) "Research on woody vegetation on levees by ERDC involved the study of two levee failure mechanisms: internal erosion and cases of simple, deep-seated slope stability….these two failure mechanisms were judged to be the most important to USACE districts in which woody vegetation might affect levee performance."

  Reviewer Note: These two levee failure mechanisms and several others are presented in Table 1 (p. 18) and Figure 2 (p. 19). However, the relative importance and frequency of occurrence of each mechanism are not discussed. Nor are explanations presented why USACE districts determined that these two failure mechanisms were judged to be the most important in which woody vegetation might affect levee performance.

Volume II: Field Studies

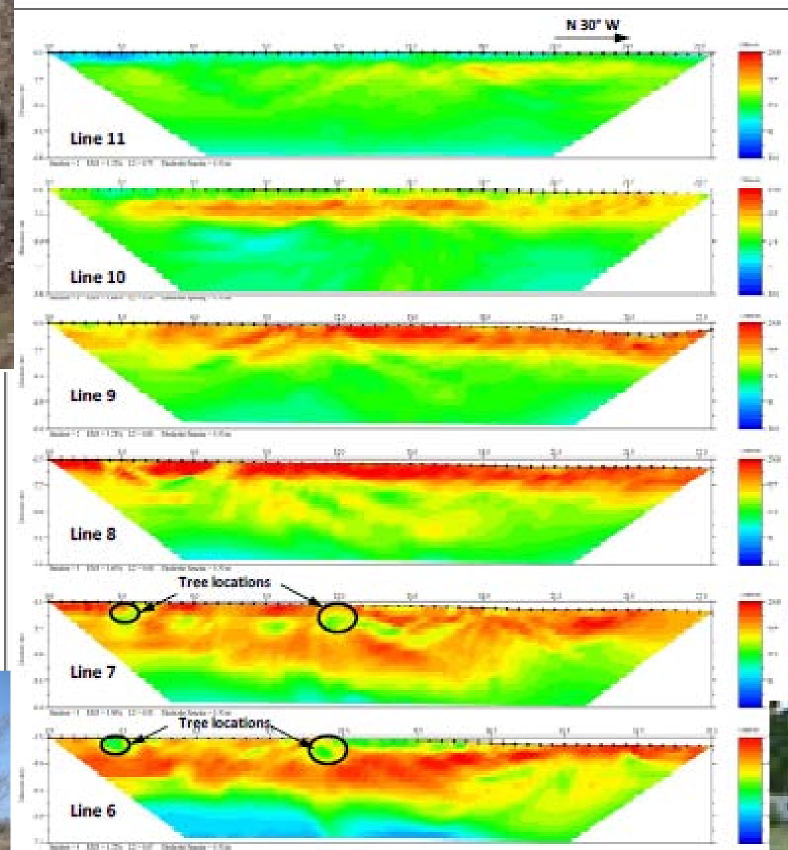


Figure 82. Inversion results for 2-D lines 6 through 11, Site B, Sacramento, CA. Ovals mark approximate tree root locations.

ERDC Field sites

- Site assessments (limited, qualitative) at 6 sites east of, or within Dallas, TX. Five levee projects plus selected trees near Vicksburg MS.
- Site characterizations at 4 sites in Western US
  - Albuquerque, NM: sandy soil
  - Burlington, WA: sandy clay levees
  - Portland, OR: levee composed of sandy soils
  - Sacramento, CA: legacy non-engineered levees built with dredge tailings, high sand content

Overview of Field and Model Studies

Table 1. Data gathered and analyses conducted for each site studied in the ERDC research.

	Seepage	Slope Stability	Geophysics	Hydraulic Conductivity	Root Characterization	Root Pullout	In Situ Soil Parameters	Field Observation
Site Characterizations								
Sacramento, CA	•	•	•	•	•		•	•
Burlington, WA	•	•	•	•		•	•	•
Albuquerque, NM	•	•	•	•	•	•	•	•
Portland, OR	•		•	•		•	•	•
Site Assessments								
New Orleans, LA			•		•			•
Boca Raton, FL				•			•	•
Lewisville, TX			•					
Danville, PA				•			•	•
Vicksburg, MS			•	•	•		•	•
Lake Providence, LA								•

Field Studies - Geological

- Geological and geotechnical information compiled from existing reports for all sites.
- This information was used to develop representative cross sections for numerical models.

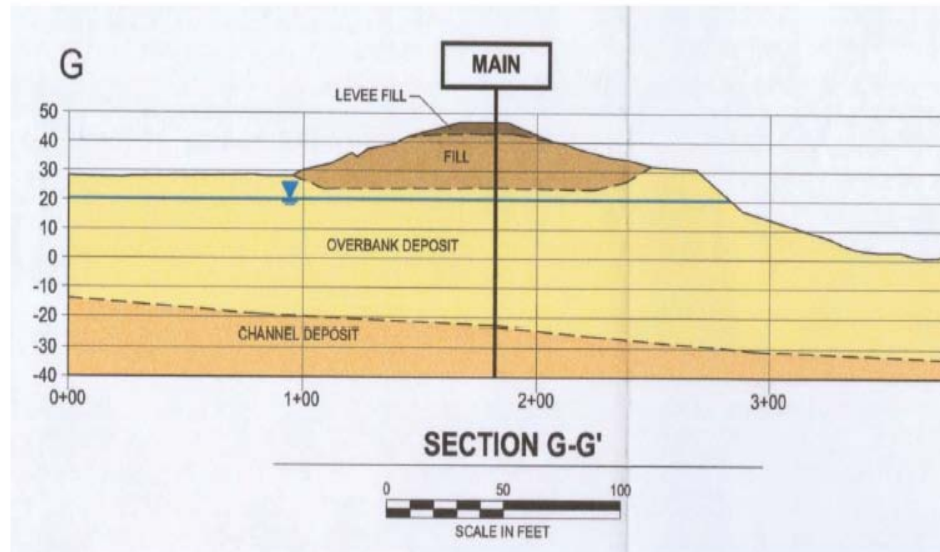


Figure 24b. Cross section G-G' used for the geotechnical evaluation (Golder Associates 2009). Levee fill (dark brown) identified in the bottom profile corresponds to new levee to be added as part of the planned improvements. Only current levee conditions were modeled by ERDC

Field Studies - Root Characterization

- Non-Invasive Techniques
  - Ground-penetrating radar
  - Electrical resistivity imaging
  - Electromagnetic induction
- Invasive Techniques
  - Subsample manual excavation
  - Full excavation with air knife and LiDAR imaging—done for one tree at Vicksburg site (not a levee)

Field Studies - Root Characterization

(Non-Invasive Techniques - Table 36)

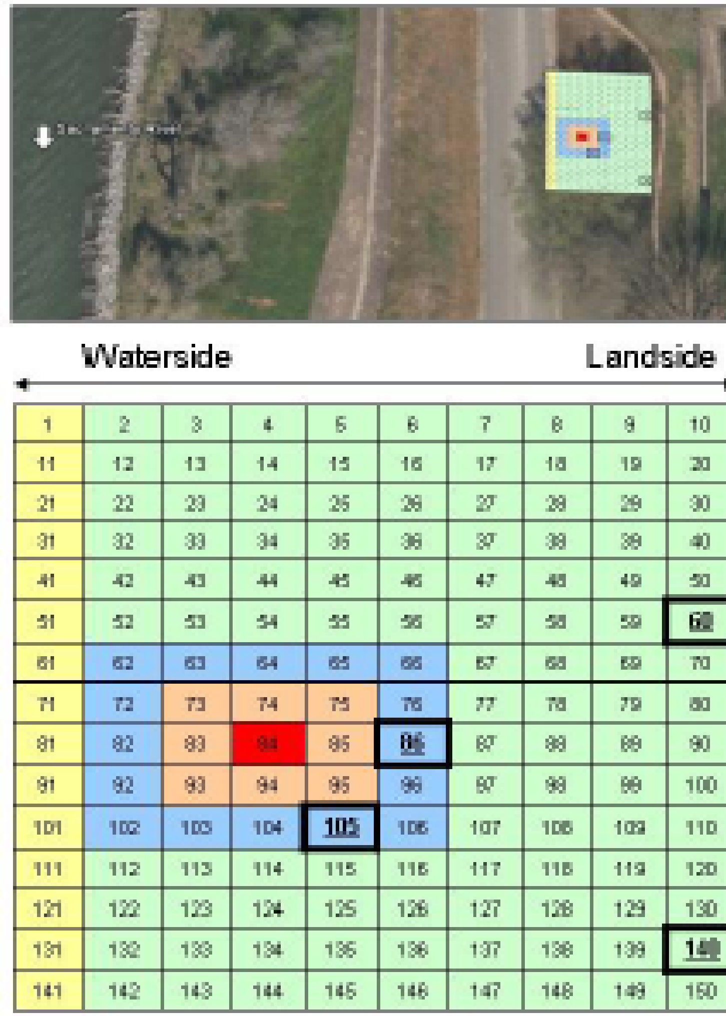
- Ground-penetrating radar tested at 5 sites. Depth for root zone found at 3 of 5 sites.
- Electrical resistivity imaging tested at 7 sites. Useful root zone dimensions determined at 4 of 7 sites.
- Electromagnetic induction tested at 5 sites. Effective at 1 of 5 sites.

Field Studies - Root Characterization

- Non - Invasive Techniques
  - Not validated or calibrated using invasive techniques.
  - Effectiveness varied widely with soil texture and soil moisture.
  - Results often contradictory and inconsistent.
  - Root zones sometimes detected, but not individual roots.

Field studies - Root Characterization

- Subsampled manual excavation of 1 m3 units selected by gridding area around a tree and selecting a subset of grid cells for excavation based on random number generation.
- Subsampled manual excavation root volume ratios 2.5% to 7.8%. Some units very close to trees.
- Sacramento average of 2.5% compares with 0.01% to 2.0% (mean 0.2%) RAR Shields and Gray (1992) for vertical profile wall mapping in driplines.



Field Studies - Soil Properties

- 9 trees at 8 locations
- Radial sampling pattern centered on individual trees and similar patterns nearby in areas without trees
- Depths of ~ 3 ft and 5 ft at most sites
- Diameter ~ 10 m-- dripline of tree
- 12 points selected at random r, θ values.

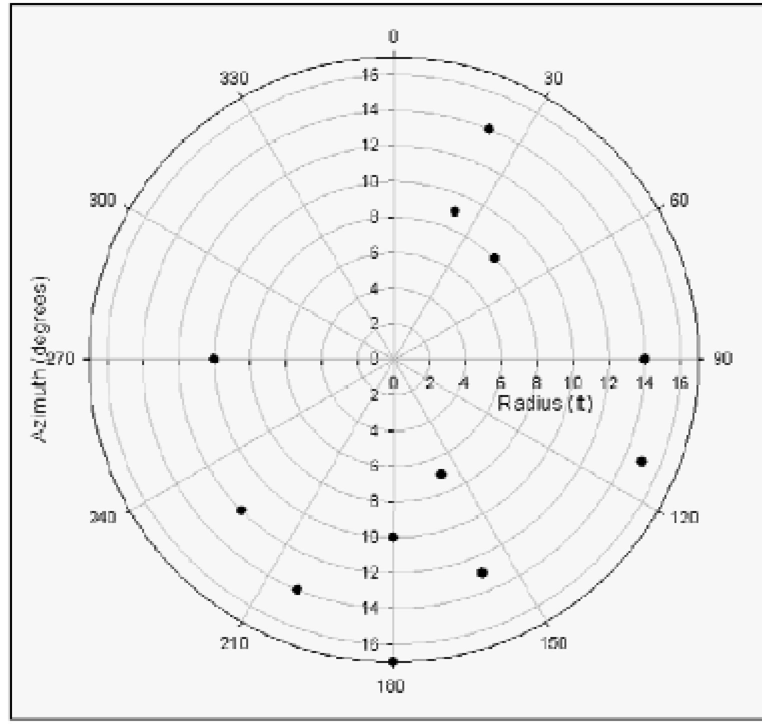


Figure 212. Plan view of hydraulic conductivity field test locations plotted in polar coordinates. The tree's center is located at the origin of the plot, and test locations are plotted along random azimuths and radii.

Field Studies - Soil Properties Measured within Radial Zones

- Soil texture, grain size, density, moisture content in lab.
- Hydraulic conductivity.
- Soil moisture probe.
- Troxler nuclear gage (soil moisture and unit weight)
- Spatial distributions of roots in these "radial zones" not measured.
- (Pg. 417) "Soil types used in ERDC modeling efforts were obtained from available sources at the time of modeling. Field testing (for soil properties) was conducted during and after completion of the numerical models for the ERDC research."

Field Studies - More Soil Properties

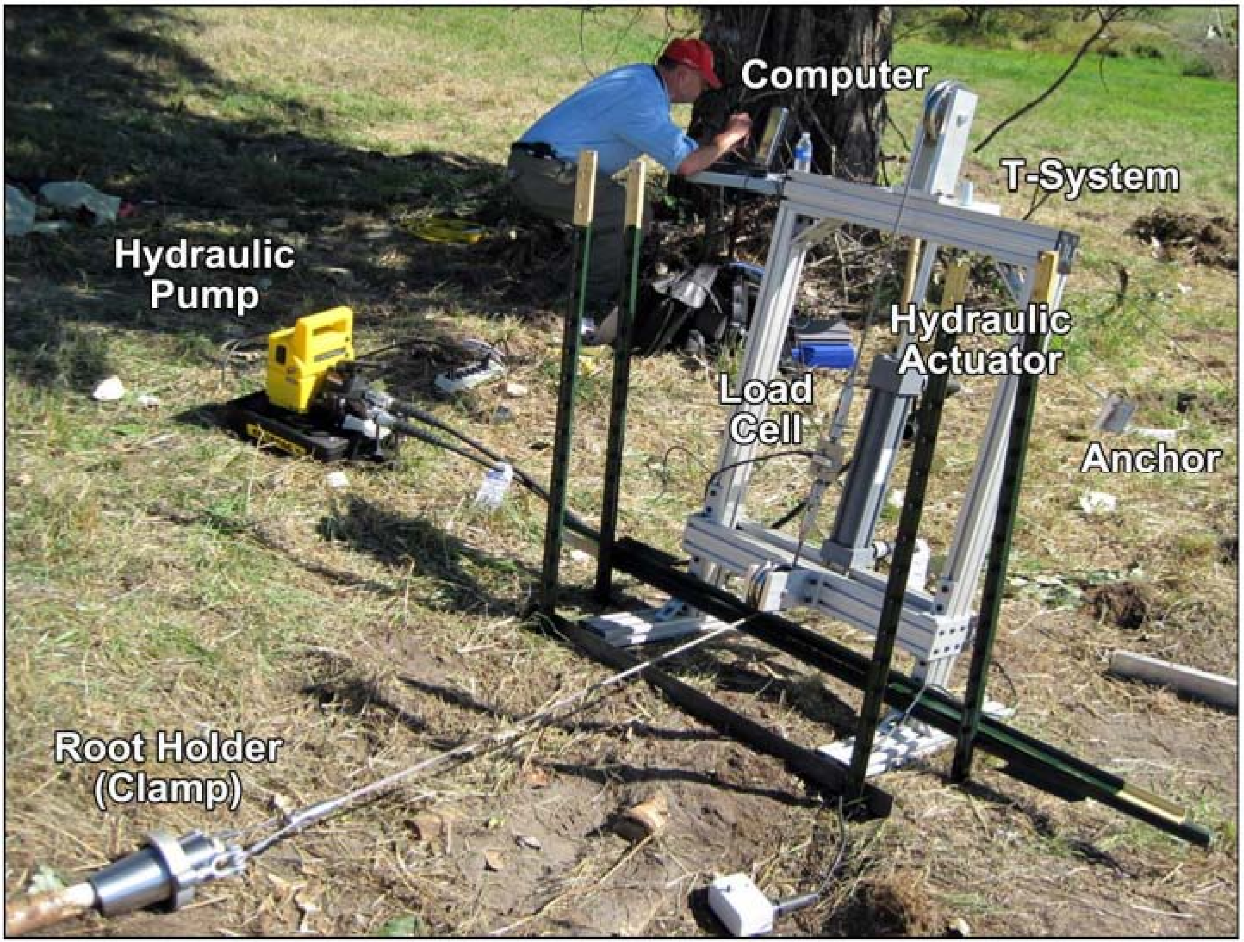
(Pg. 5) “For both site characterizations and site assessments, field testing of in situ soil moisture and density were conducted with a Troxler nuclear density and soil moisture gage to verify the boring data values and assess the changes in soil density and moisture under the tree canopy as a function of distance from tree, as well as non-vegetated zones along the levee" (emphasis added).

- Troxler nuclear density and soil moisture measurements made in grid on levee slopes at 2” increments down to a depth of 12”

Reviewer Note: It is unclear why the Troxler data are important given their shallow depth.

Field Studies - Root Strength

(Using a Root pull out device – pictured below)



Field Studies - Root Strength Cont'd

- Pull out studies performed at three sites under dry conditions:
  - Portland, OR
  - Burlington, WA
  - Albuquerque, NM
- Maple, alder, Oregon ash, cottonwood, and cedar

Field Studies - Findings

Reviewer Note: Statistics (areas w/ trees vs. w/out trees) showed no evidence that tree roots influence the average hydraulic conductivity of a soil layer.

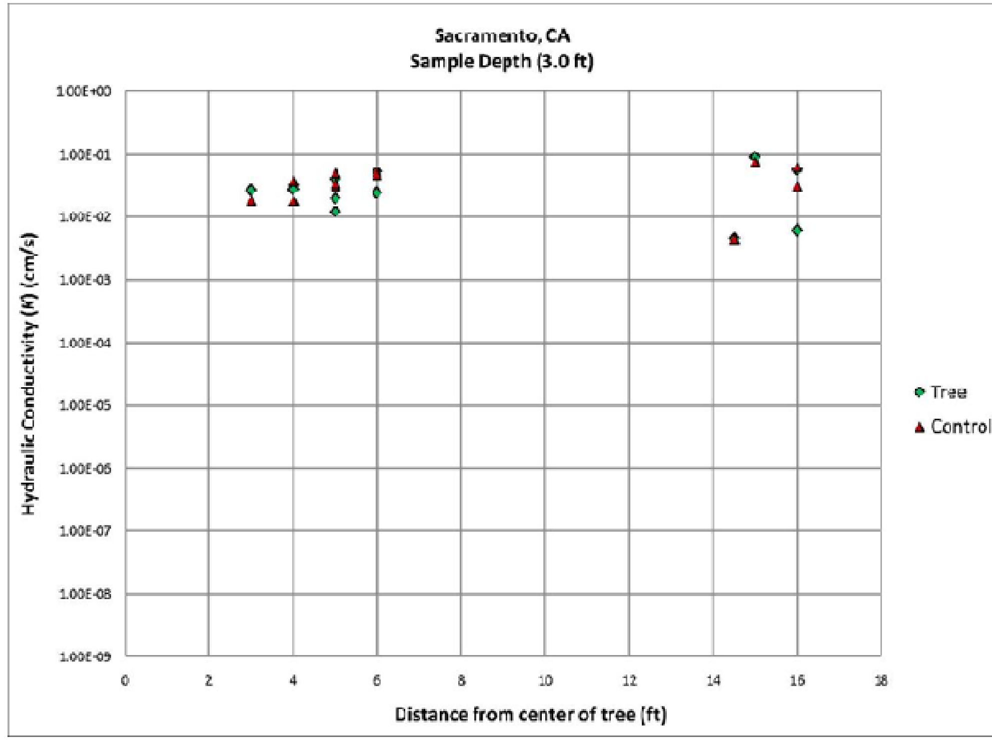


Figure 222a. Hydraulic conductivity calculated from in situ permeameter tests at a depth of 3.0 ft, Sacramento, CA.

(Pg iii) "Only one test showed evidence of an existing macropore associated with a tree site."

Field Studies – Findings Cont'd

- Tested roots in narrow range of larger diameters 0.7 in to 2.5 in. No effect due to species, but location and diameter were important.
- Work by others shows small roots (< 20 mm diam) have large contribution to soil strength at least at shallow depth.
- Root pullout strength (force required to pull root out of soil), not tensile strength (force required to break a root), was used in numerical slope stability analysis.

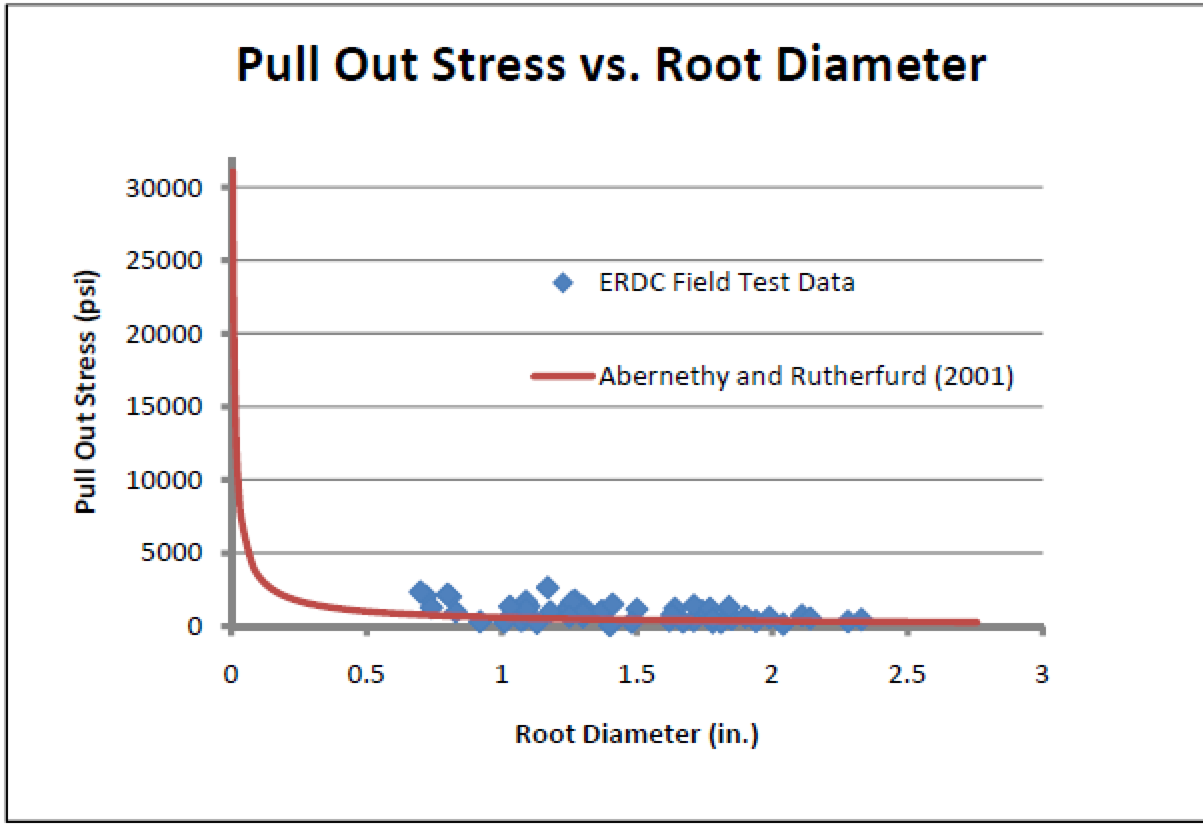


Figure 251. Comparison of ERDC and Abernathy and Rutherford (2001) pullout stress vs. root diameter tests.

<u>Reviewer Note:</u> Use of root pullout strength reasonable because failure tended to occur by slip or pullout.

Volume III: Numerical Modeling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Initial Research into the Effects of Woody

Vol III: Numerical Modeling

Volume IV of IV: Summary of Results and Conclusions

Maureen K. Corcoran, John F. Peters, Joseph B. Dunbar, Jose L. Llopis, Fred T. Tracy, Johannes L. Wibowo, Janet E. Simms, Christopher E. Kees, S. Kyle McKay, J. Craig Fischenich, Matthew W. Farthing, M. Eileen Glynn, Bryant A. Robbins, Ryan C. Strange, Martin T. Schultz, Joan U. Clarke, Thomas E. Berry, Charles D. Little, and Landris T. Lee

July 2011

Numerical Modeling - Executive Summary

With respect to seepage analyses….

(Pg. IV) "The results from these analyses are <u>specific only to the levees studied for this research</u>." (emphasis added).

(Pg. VI) "In this study, reductions in factor of safety reflect specific conditions and may not represent the worst case scenario at these sites. Because of the extreme variability in geology, tree species, climate, and soils, the impact of trees on levees must be analyzed on a <u>case-by-case</u> basis". (emphasis added).

<u>Reviewer Note:</u> Statements highlight the variability of levee conditions and need for site-specific analysis to determine impacts.

Numerical Modeling - Executive Summary

(Pg. III) ERDC research used SEEP2D for three analyses in the seepage modeling. These analyses included:

1. Conducting a sensitivity analysis for hydraulic conductivity as it affects the groundwater flow field. Hydraulic conductivity for a rectangular block representing a tree root zone was varied across several orders of magnitude (Pg IV).
2. Producing a random macropore system by randomly assigning conductivities varying across four orders of magnitude to cells of a finite element grid within a rectangular block representing a tree root zone.
3. Representing a root as a defect extending from the surface to the base of the blanket.

<u>Reviewer Note:</u> These are scientifically interesting approaches, but tended to produce inconclusive results.

Numerical Modeling Cont'd

- Levee geometry and soil characteristics from existing geotechnical reports.
- Wind loads and tree weights computed using empirical equations from literature.
- Except for root strength, numerical models <u>did not use data from levee vegetation field studies.</u>
- <u>Root zone dimensions were based on geophysical studies (5 ft deep x 6 ft x 6 ft).</u>
- Root area ratio for Sacramento Pocket site taken from Gray et al. (1991), but note varying values for RAR on p184 (0.5%) & p187(0.2, should be 0.2%). In models of other sites, the root area ratios were based on data gathered by Norris and Greenwood (2006).

Numerical Modeling Cont'd

- Critical conditions for slope stability and seepage identified using 2-D simulations of representative levee cross sections at the 4 western sites:
  - Under flood loads
  - Conditions nearing failure
  - Landside—steady state seepage (transient conditions also analyzed)
  - Riverside—rapid drawdown
- These conditions were then used to reassess levee performance with differing locations for <u>single trees.</u>

Numerical Modeling Cont'd
Simulation of Tree Effects - 2D

- Seepage (SEEP2D) and slope stability (UTEXAS4) models.
- Single trees on levee cross section.
- Sensitivity analyses:
  - No woody vegetation
  - Soil properties modified by woody vegetation
- Seepage analysis run first. Phreatic surface from seepage analysis used as input for slope stability program.

Numerical Modeling Cont'd
Soil Properties Modified by Vegetation

- Simulated in seepage model three ways
- In all three, root zone assumed to be a <u>uniform</u> rectangular block 6 ft wide x 5 ft deep:
  1. Modified hydraulic conductivity within block (0.001 to 1000) where 1 = no veg effect. This "no veg effect" hydraulic conductivity value was apparently computed (not measured) from soil type based on the van Genuchten equation.
  2. Simulated macropore heterogeneity in the rectangular block by breaking the block into small elements and assigning a random value for hydraulic conductivity to each element that was between 0.01 and 100 times the no veg effect value.
  3. Represented a root as a defect extending from the surface to the base of the blanket.
- Contribution of roots to soil strength simulated in somewhat unorthodox way. Fiber bundle approach not used. "Reinforcing roots" inserted in model around the 5 x 6 x 6 root zone, but how the number and size of these roots was set is not clear.

<u>Reviewer Note:</u> Concentrated seepage "which may occur around a root" was not considered.

Compare “rectangular block” with root architectures exposed by Dr. Alison Berry

(Pg. iv) “The extended root system was depicted as a uniform area of low hydraulic conductivity, which is an extreme representation that may not reflect actual field conditions.”

(Photo CLVRP 2010)

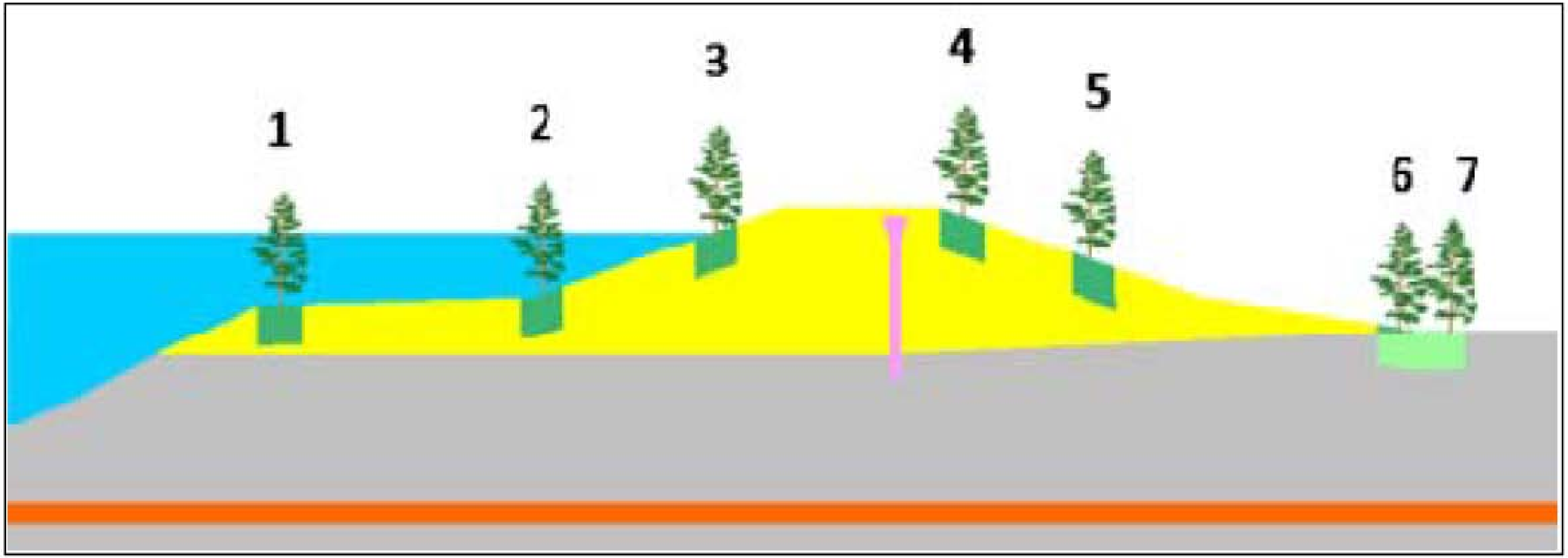
<u>Reviewer Note:</u> Many root distribution studies have reported root densities decline exponentially with depth below soil surface.

Numerical Modeling Cont'd
Tree Locations Simulated in Models

The rectangular block in models was located at each of four locations on both riverside and landside:

- levee toe
- beyond the levee toe
- levee slope
- levee crest

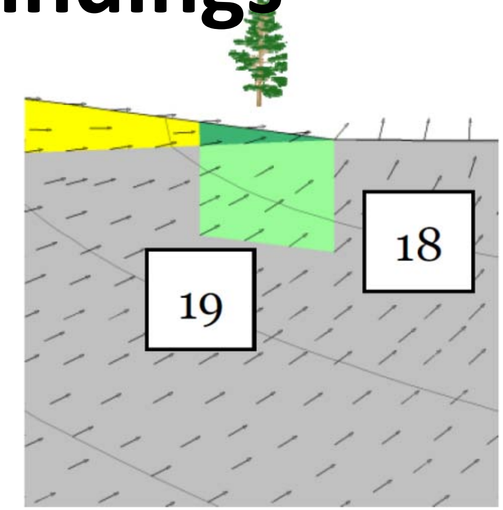
Numerical Modeling Cont'd
Schematic of Tree Locations



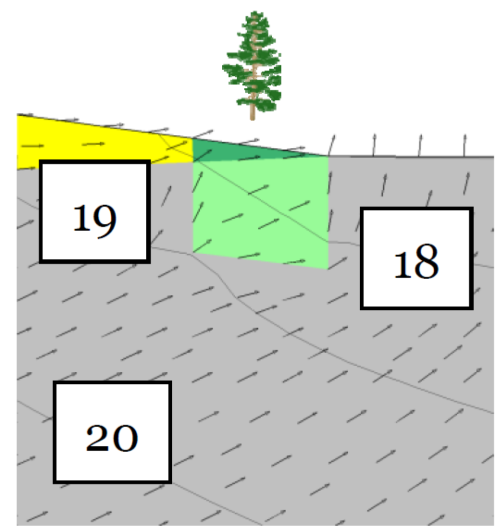
Tree position and water elevation scenarios

Numerical Modeling Cont'd
2-D Seepage Analysis Findings

- Sensitivity analysis
- The volume around a root zone was assigned various values of hydraulic conductivity (varied across 4 orders of magnitude) with conditions within the zone assumed uniform.
- Root zones generally affected the flow field within their immediate vicinity, but have virtually no influence on the overall flow field.
- The most likely impact on the flow path or critical gradient occurred when the tree was located at the toe of the levee, but this impact depended on the degree to which the tree altered hydraulic conductivity of the soil.
- Changes in hydraulic conductivity on the riverside do not appear to affect the landside flow conditions.



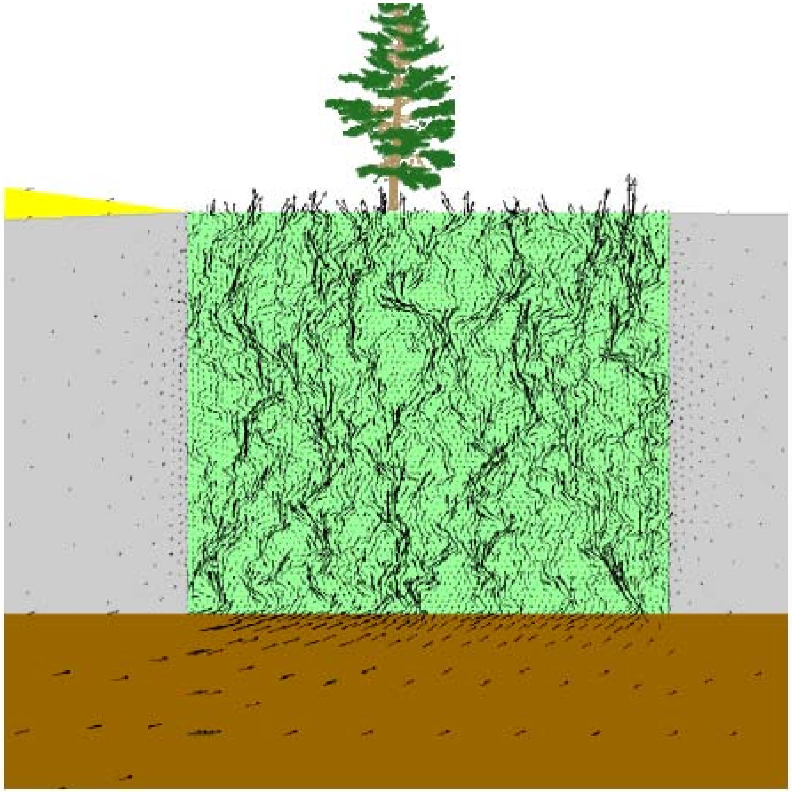
(b) $\beta = 1$ ($k_{veg} = 1\ k_{no\text{-}veg}$).



(h) $\beta = 0.01$ ($k_{veg} = 0.01\ k_{no\text{-}veg}$).

Numerical Modeling Cont'd
2-D Seepage Analysis Findings

- Representation of vegetation influence as randomly distributed hydraulic conductivity within the block-- "macropore heterogeneity".
- Resulting seepage velocity vectors show that a random heterogeneous zone can have flow paths that support large flow velocities.
- (Pg. iv) "However, research does not exist on whether high velocities result in the initiation of internal erosion."



Vectors in root zone larger than for surrounding soils (Pg. 137-138).

Numerical Modeling Cont'd
2-D Seepage Analysis Findings

Representation of root as defect in blanket – findings:

(Pg v) "Analyses were conducted for Burlington, WA, Portland, OR, and Albuquerque, NM. Based on these analyses, the probability of initiation of internal erosion is negligible from woody vegetation at the toe of the levee for the Burlington and Portland sites. The results for Albuquerque yielded a factor of safety slightly higher than 1.0 but the probability of internal erosion occurring is negligible to 0.25." (emphasis added)

Numerical Modeling Cont'd
2-D Slope Stability Analysis

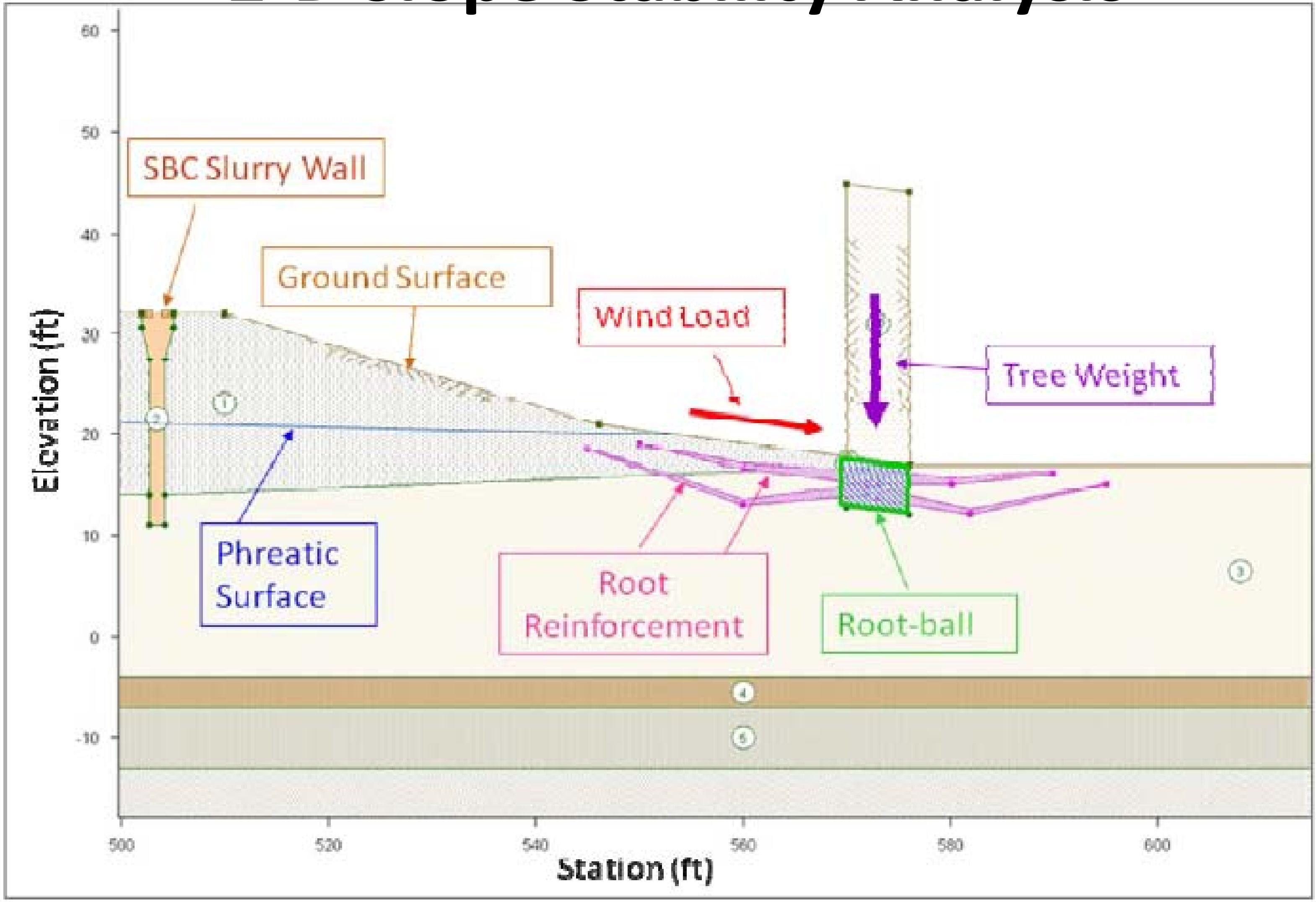


Figure 174. Conceptual diagram of tree and levee interaction in slope stability analysis.

Numerical Modeling Cont'd
Tree Location Important to Slope Stability

(Pg. V) "In general, this study observed that <u>trees on the upper part of the slope decreased the factor of safety</u> because they add weight. Trees <u>near the toe increased the factor of safety</u> because of the reinforcing effects of the roots and the increased counterweight effect of the tree to slope movement. <u>Trees at midslope had lesser effect</u> on the factor of safety because they acted as a load, but not a counterweight, and the roots are too shallow to reach the failure zone within the midslope region".
(emphasis added)

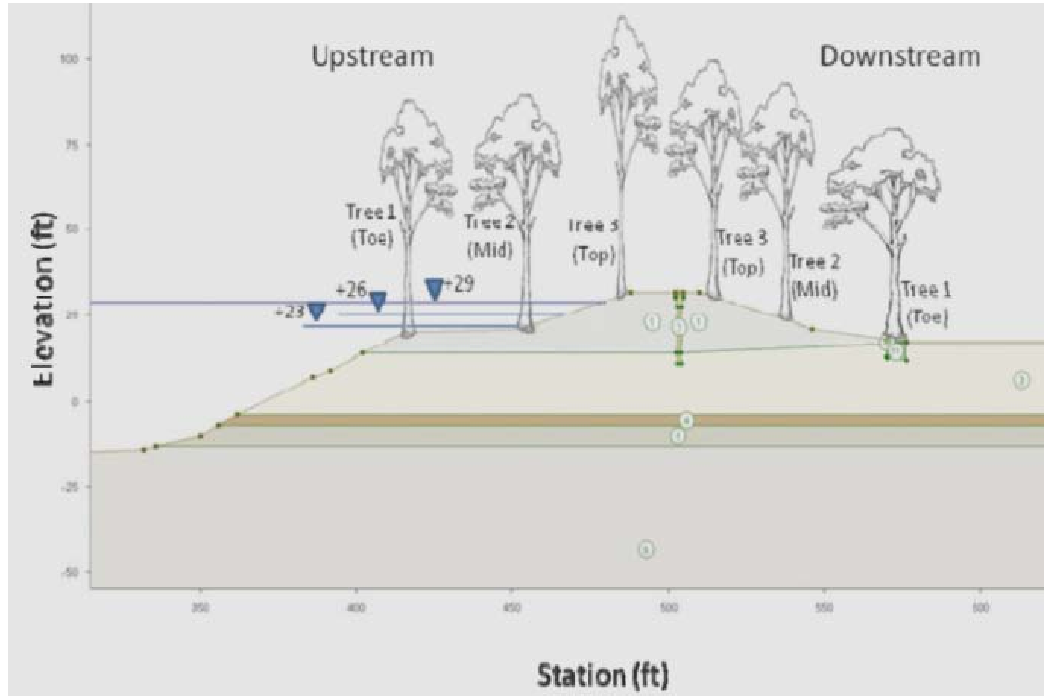


Figure 179. Tree positions and water levels used in the sensitivity analysis for the slope stability analyses, Pocket Levee, Sacramento, CA.

<u>Reviewer Note:</u> Similar findings reported by Norris and Greenwood (2006) and by Danjon and others prior to this study.

Numerical Modeling Cont'd
Tree Impacts on Slope Stability were very small at all Locations:

Table 80. Factor of Safety for the Pocket Levee (riverside) with no tree, three different tree locations, and three different flood water levels.

Failure Criteria	Water Level	Factor of Safety			
		No Tree	Tree at toe	Tree at midslope	Tree at top slope
1	23	2.00	2.11	2.04	2.13
	26	2.05	2.15	2.07	2.17
	29	2.10	2.23	2.12	2.32
2	23	2.08	2.12	2.05	2.07
	26	2.13	2.20	2.10	2.10
	29	2.21	2.30	2.18	2.25
3	23	2.15	2.21	2.15	2.14
	26	2.24	2.30	2.22	2.21
	29	2.34	2.41	2.32	2.36

Numerical Modeling Cont'd

Adaptation of slope stability analysis for sandy soils

(Pg 185) "In most slope stability analyses, finding the absolute minimum factor of safety is a goal. This is easily accomplished in UTEXAS4 through the use of the built-in automated search routine, in which a floating search grid is used to search all possible circle locations However, in sites with cohesionless soils, this feature is of little use because the failure circle with the lowest factor of safety is always a shallow, local failure circle near the surface."

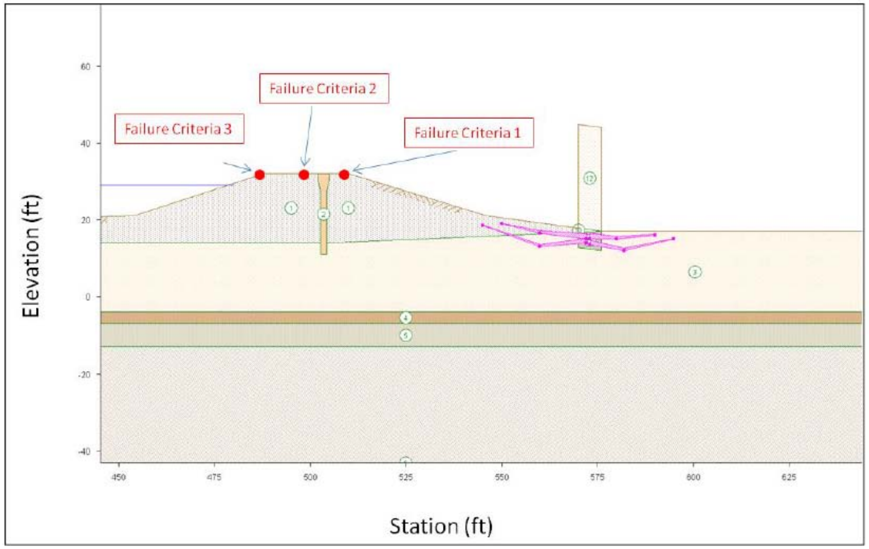


Figure 175. Three failure criteria used for calculating the factor of safety on the landside at the Pocket Levee, Sacramento, CA.

"To gain an understanding of how the tree position affected overall levee stability, three failure criteria were defined by limiting the software's search routine to failure circles passing through three points (Figure 175). These limitations are designated as failure criteria because they determine which factor of safety value is identified as being closest to failure. While this procedure may not find the absolute minimum factor of safety for a given slope, it will serve as definitive criteria for quantifying the effects of trees on levees."

<u>Reviewer note</u>: Probably reasonable approach for the problem at hand, but slope failures in sandy soils tend to be shallow, planar failures and root reinforcement will likely have greater positive impacts on shallow failure zones (Shields and Gray 1992).

Numerical Modeling Cont'd
2-D Slope Stability Analysis Findings Regarding Wind Loads

(Pg. vi) "…..when wind speeds greater than 40 MPH are considered, the factor of safety decreases for all tree locations evaluated for this study."

Reviewer Note: Representation of wind load may not accurately reflect real conditions:

(Pg. 193) "Wind was applied in all directions but it became apparent after many model runs that UTEXAS4 could not model a moment."

Reviewer Note: Wind load was represented as a force acting on root ball or base of tree, but it's not clear if only downslope wind forces were analyzed.

Numerical Modeling Cont'd
Typical Impact of Wind Loads on Factor of Safety

Table 81. Factor of Safety for the Pocket Levee, Sacramento, CA, (landside) with three different tree locations, and flood water elevation at 29 ft with varying wind speeds. The crown area of the cottonwood is 2625 ft^2.

Failure Criteria	Water Level	Wind Speed (mph)	Wind Pressure (lb/ft^2)	Wind Load (lb)	Factor of Safety			
					No Tree	Tree at Toe	Tree at MidsSlope	Tree at Top Slope
2	29	0	0	0	1.60	1.72	1.56	1.52
		5	0.1	44	1.60	1.72	1.56	1.52
		15	0.6	263	1.60	1.71	1.55	1.51
		25	1.7	744	1.60	1.67	1.53	1.49
		40	4.2	1838	1.60	1.61	1.48	1.45
		60	9.5	4156	1.60	1.46	1.37	0.66
		75	15	6563	1.60	1.31	1.26	0.42

Numerical Modeling Cont'd
Simulation of Tree Effects – 3-D

- Only for Sacramento and Burlington, WA sites.
- Selected "worst case" scenarios were selected for high resolution 3-D seepage and stability analysis.
- Existing "geotechnical reports" used to create input data files.
- The 3-D model modified the 2-D geometry to include three woody vegetation zones located at the toe (landside toe, Sacramento; riverside toe, Burlington) and positioned 20 ft apart.

Numerical Modeling Cont'd
3-D Simulation Findings

(Pg vi)" Local 3-D effects were observed in the flow field around the zones, but <u>resulted change was not apparent to the global flow field, location of the seepage face, or pore pressure gradients</u>. The lack of change is attributed to the particularly shallow depth of the zones relative to the deeper confining layers" (emphasis added).

Numerical Modeling Cont'd Recommendations/Outcomes

- Focused regional studies needed in representative areas of the US.

Reviewer Note: In Volume 1 "Project Overview" authors emphasize "The Scope of Work (SOW) strongly supports the idea that focused studies of woody vegetation on levees should be conducted in representative areas of the United States and that these studies consider the different geographical and physical characteristics at each site." The Numerical modeling volume repeatedly stressed that the model results were not generally applicable due to this fact.

- Vegetation can impact levee stability and seepage, but most of the cases analyzed showed effects were positive or very small.

Numerical Modeling Cont'd Recommendations/Outcomes

ERDC report notes more study warranted on….

- Impact of woody vegetation on the progression of piping.
- Effects of dead trees/roots.
- Levees consisting of clay were not included in the ERDC numerical analyses.
- Contributions of windthrow and animal burrows to seepage.

Reviewer Note: the effect of vegetation cover on the population density of burrowing mammals is also a germane topic.

- Impact of woody vegetation within a levee channel on the hydraulic conveyance of a river.
- Prevention of growth of protective grass cover beneath a tree.
- Contribution of woody vegetation to scour and erosion.

Reviewer Note: Some types of woody cover may prevent scour and erosion.

- The effect of woody vegetation on levee inspection, maintenance, and accessibility to the levee.

Volume IV: Summary of Results and Conclusions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Initial Research into the Effects of Woody Vegetation on Levees

Volume IV of IV: Summary of Results and Conclusions

Maureen K. Corcoran, John F. Peters, Joseph B. Dunbar, Jose L. Llopis, Fred T. Tracy, Johannes L. Wibowo, Janet E. Simms, Christopher E. Kees, S. Kyle McKay, J. Craig Fischenich, Matthew W. Farthing, M. Eileen Glynn, Bryant A. Robbins, Ryan C. Strange, Martin T. Schultz, Joan U. Clarke, Thomas E. Berry, Charles D. Little, and Landris T. Lee

July 2011

Reviewer Note: Much of the material in this volume is also found in the executive summary sections in other volumes. Some comments are also somewhat redundant.

Summary of Results and Conclusions Cont'd

(Pg. 3, Volume I) "The variability in levee systems, soil profiles, geography, and tree species is tremendous and difficult to analyze even with extensive research programs. Therefore, results from this research are not applicable to all levee system or tree species."

<u>Reviewer Note:</u> Conclusion could support a more flexible approach to vegetation management taking local conditions into account.

Summary of Results and Conclusions Cont'd
2-D Seepage Analyses

(Pg 21) "…trees located on the slopes above the phreatic surface had a limited effect on the seepage, the greatest effect being felt from trees at the landside levee toe."

(Pg 22) "…only trees just beyond the toe of the levee or at the bottom of the de-watered drainage ditch made any appreciable difference to the value of the exit gradient for the cross sections considered in this study. "

Specifically….

"The case where the root system causes a reduction in hydraulic conductivity by more than a factor of 10 shows an increase in hydraulic gradient as a result of low hydraulic conductivity of the root zone blocking the flow of water."

Summary of Results and Conclusions Cont'd
3-D Seepage Analyses

(Pg 22) "Changes in pore pressure caused by differences in hydraulic conductivity of less than an order of magnitude are small, especially if 3-D geometries are considered. In general, the effect of a single tree in three-dimensional flow on levee performance is smaller than in a two-dimensional flow field."

Summary of Results and Conclusions Cont’d
Stability Analyses

(Pg. V) “In general this study (2-D stability analyses) observed that trees on the upper part of the slope decreased the factor of safety because they add weight. Trees near the toe increased the factor of safety because of the reinforcing effects of the roots and the increased counterweight effect of the tree to slope movement. Trees at midslope had lesser effect on the factor of safety because they acts as a load, but not a counterweight, and the roots are too shallow to reach the failure zone within the midslope region.” (emphasis added)

Reviewer Note: Effects on safety factor tended to be <10%. Note that the seepage analyses showed negative impacts associated with trees near toe. These effects are also small for the cases examined.

(Pg. VI) “…… when wind speeds greater than 40 MPH are considered, the factor of safety decreases for all tree locations evaluated in this study (top, bottom and midslope).”

Reviewer Note: Based on tables and figures in Vol III, wind effect only important for trees at top of slope and winds $\geq$ 60 mph.

Summary of Results and Conclusions Cont'd

(Pg. VI) "In this study, reductions in factor of safety reflect specific conditions and may not represent the worst case scenario at these sites. Because of the extreme variability in geology, tree species, climate, and soils, the <u>impact of trees on levees must be analyzed on a case-by-case basi</u>s. However, this study does reveal that the tree weight, tree location, root system, and wind loads are all significant parameters that must be taken into account when evaluation the effect of a tree on slope stability for a particular site." (emphasis added)

(Pg. VI). "The results from these analyses are specific only to the levees studied for this research."

<u>Reviewer Note:</u> Conclusions could support a more flexible approach to vegetation management that could take local conditions into account.

Summary of Results and Conclusions Cont'd

(Pg. VI) "There are many other possible effects of woody vegetation on a levee that were not studied in this research. Efforts reported in this research were focused on living, healthy woody vegetation. This research did not address levee systems with the presence of dead, woody vegetation and decaying roots."

<u>Reviewer Note:</u> This is a critical area for further study because large scale tree removals will significantly <u>increase</u> the presence of decaying roots unless there is a way to safely and effectively remove roots when trees are removed.

<u>Reviewer Note:</u> Is it possible to convert existing tree cover to grass cover in a safe and cost effective fashion? How can environmental effects of such actions be mitigated? More study needed on these questions.

Reviewers

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Gray and Shields were principal investigators for a US Army Corps of Engineers sponsored study of effects of trees on Sacramento River levees in the 1980s.

About the CLVRP

The California Levee Vegetation Research Program (CLVRP) is a partnership of federal, state, and local agencies formed to conduct original scientific research to address vegetation policy issues affecting the state and federal levee system in the California Central Valley.

The CLVRP began in 2009 and is funded by the California Department of Water Resources and the Sacramento Area Flood Control Agency.

Sponsoring/Advisory Agencies of the California Levee Vegetation Research Program